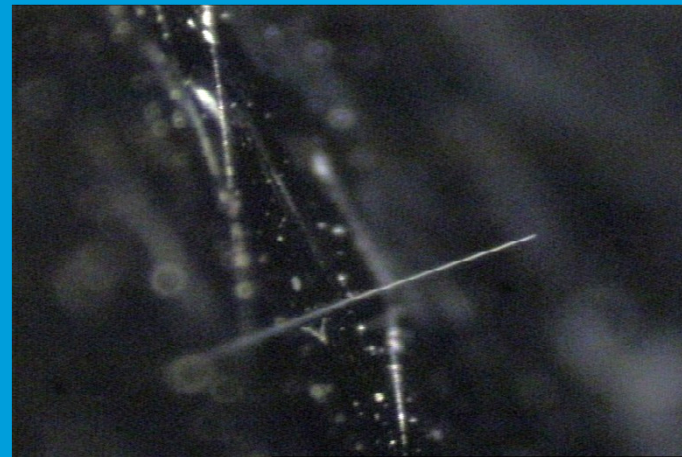




Sn whiskers and their mitigation for space, aerospace and defence electronics

Martin Wickham, Kate Clayton, Chris Hunt
- National Physical Laboratory, UK

Barrie Dunn - ESTEC



- **EMPPS_5, Noordwijk**
- **20 - 22 May 2014**

martin.wickham@npl.co.uk
www.npl.co.uk/ei

Whisker Work at NPL (many part-funded by ESA)

- Databank of Sn whiskers in commercial components
- Sn whisker mitigation using conformal coatings - ESA
- Electrostatic attraction of whiskers - ESA
- Whisker contact resistance measurement - ESA
- Whisker oxide thickness characterisation - ESA
- Current carrying capacity of whiskers - ESA
- Whisker oxide breakdown - ESA
- Electrical resistance of whiskers - ESA
- Whisker growth under electric fields
- Whisker mitigation by coatings using an SOIC component test vehicle
- Retermination of components by hot dipping (refinishing)

ESA Guidelines for Creating a Lead-Free Control Plan ESA-STM-281

- Many of the past NPL Whisker Studies have been part-funded by ESA
- Those individual Study Results were incorporated into ESA-STM-281 Appendix A by the Working Group
- Data for "Mitigation Strategies for Tin Whisker Reduction" partly sourced from NPL Studies
 - e.g. mitigation by means of conformal coatings, hot dipping....
- On-going and Future NPL Studies can help refine STM-281
 - Increased risk of failures: electrostatic attraction, growth under electric fields
 - Decreased risk, older whiskers have thicker oxide coverage/increased electrical breakdown
- Data bank results will be of interest (ESA not a participant) and a future study involving growth under vacuum would be of special interest.

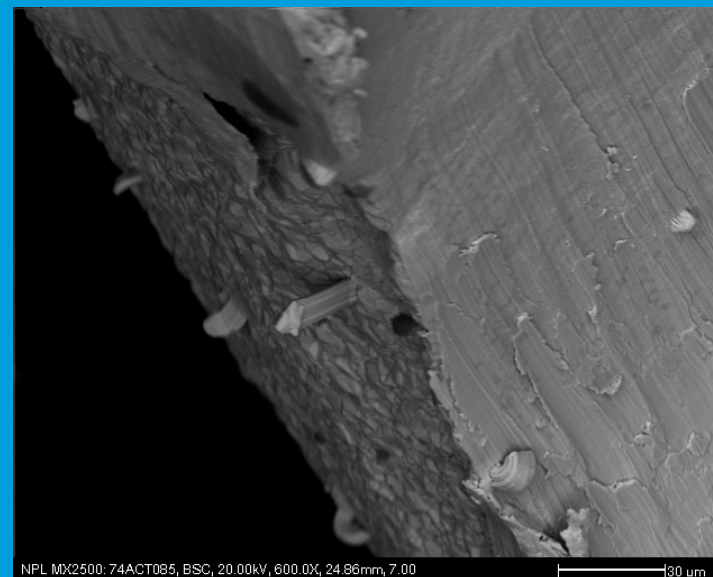
Tin Whisker Databank

Martin Wickham

Tel : +44 (0) 208 943 7150

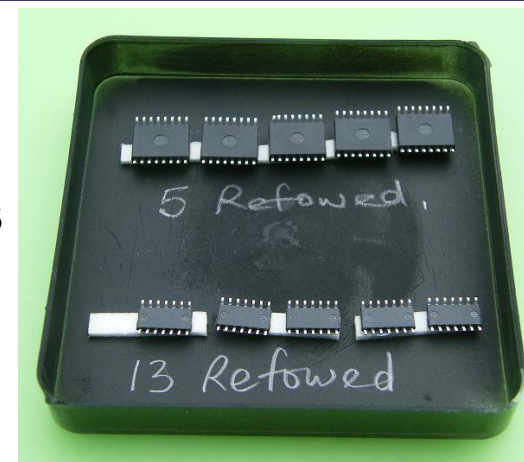
Mobile : +44 (0) 7831 629293

Email: martin.wickham@npl.co.uk



Sn Whisker Databank

- Acquire commercial components
- Store at NPL at ambient
- Visually inspect for Sn whisker every 12 months
- Started 2009
- Stereo zoom microscope (25x to 100x) with ring illumination
- Random selection
- Total 78 different components
 - 63 SOIC/SSOP
 - 3 x gull wing optocouplers, 2 x tantalums, 2 x TQFP, 4 x DIP, 4 x SOT23/223
- 27 different manufacturers
- 14 countries of origin

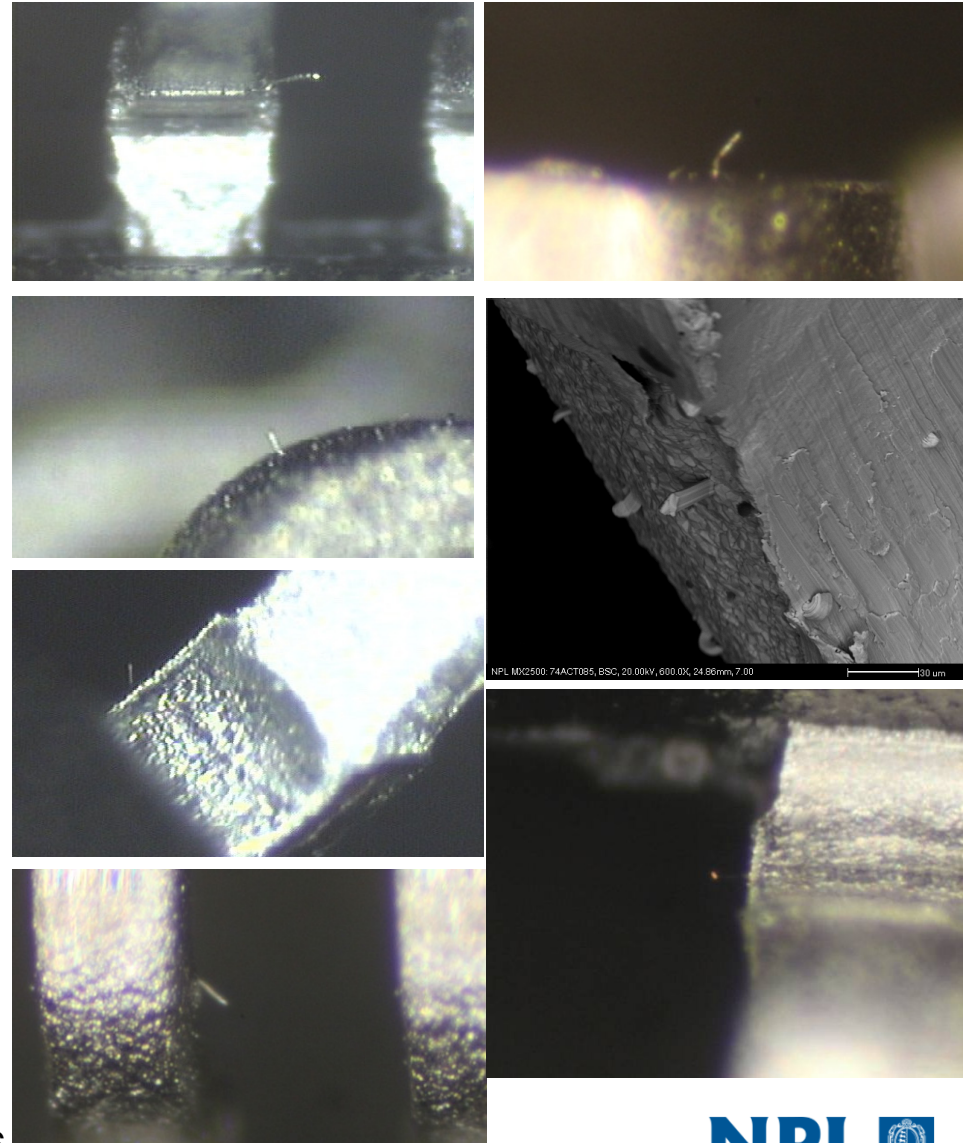


Partners

- Aero Engine Controls
- MBDA (UK) Ltd
- BAE Systems
- Thales Missile Systems
- HMGCC

Databank Summary To Date

- Whiskers noted on 10 different component types inspected (78 total)
- Whiskers noted on components from 5 different countries of origin (14 total)
- Whiskers noted on components from 7 different suppliers (27 total)
- No whisker greater than 50% of lead gap spacing (End of year 1)





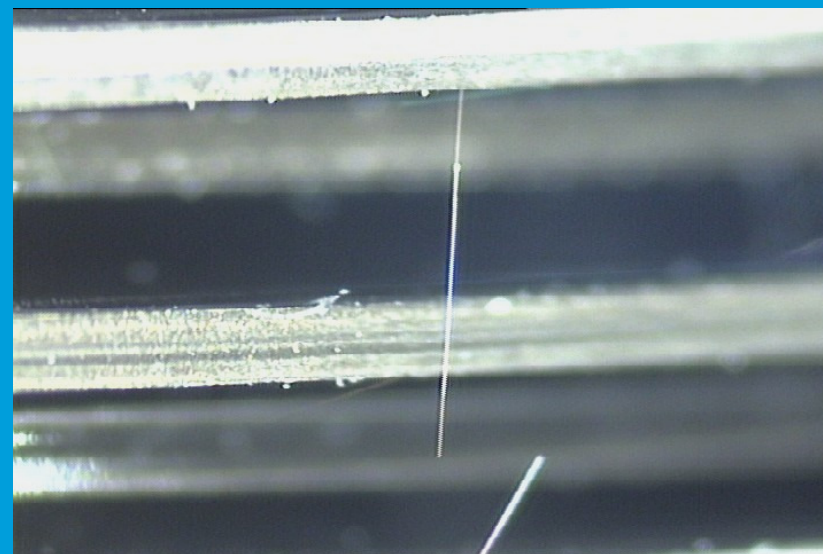
NPL Whisker Mitigation JIP Project Five years on

Martin Wickham

Tel : +44 (0) 208 943 7150

Mobile : +44 (0) 7831 629293

Email: martin.wickham@npl.co.uk



NPL Whisker Mitigation JIP Project

- Project formed a group of coatings suppliers and end-users to develop test method, to explore conformal coating Sn whisker mitigation.
 - Based on suitable industry representative materials (Olin 194 Cu leadframe).
 - Electrical detection of whiskers shorting between adjacent conductors.
 - Range of commercial and innovative chemistry formulations
- Special chemistry used by NPL in benchtop electroplating rig
- Whiskers up to 1mm in length in less than 4 weeks

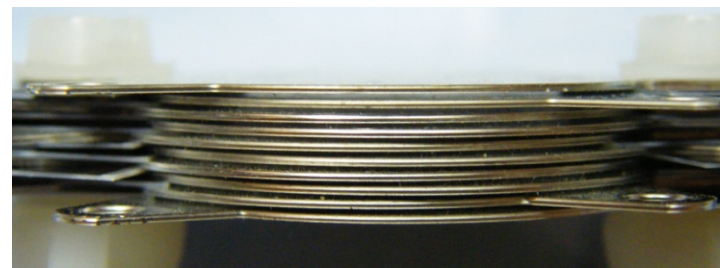
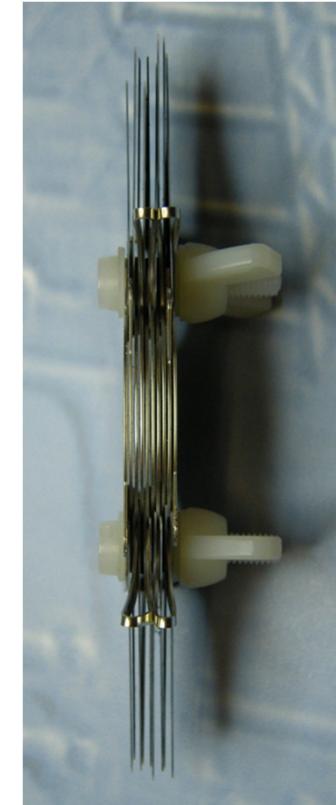
Partners:

BIS, Elantas Beck GmbH
Henkel Loctite Adhesives
H K Wentworth Ltd
Humiseal Europe
ESA, General Dynamics
Goodrich, HMGCC
MBDA (UK) Ltd
Rolls Royce Marine
CML Microcircuits Ltd
Selex, Thales

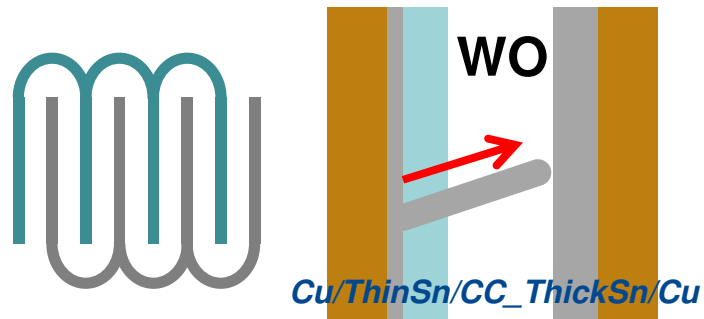


Parallel Plate Test Vehicle

- Etched copper sheet (Olin 194) to NPL design
- Design can be concertinaed to form parallel plate test vehicle
- Necking of interconnect to define bend position
- Coatings applied by end-user/supplier in flattened state
- 0.25mm spacing
- 10 plate stack
- 4500mm² of overlap



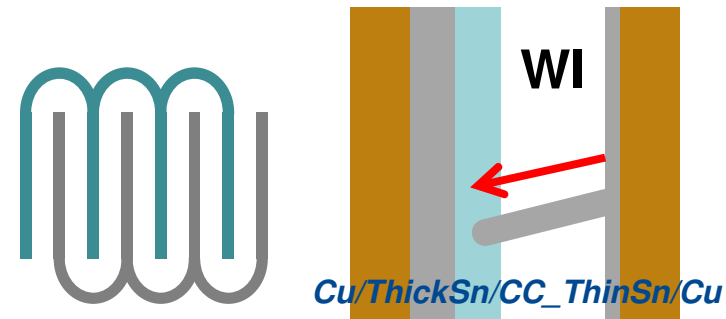
CCWM Parallel Plate Samples



Type 1: Monitors whisker penetration out from under coating

Plate 1: Thin Sn, conformally coated

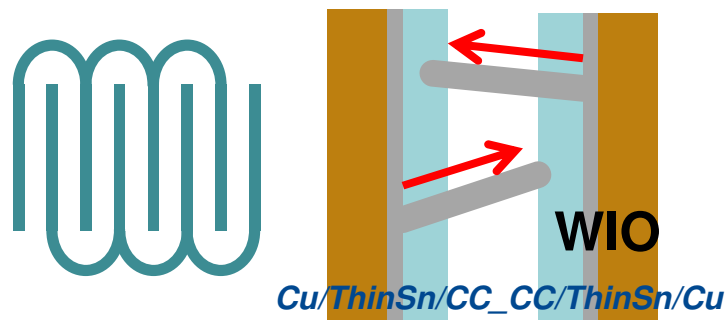
Plate 2: Thick Sn, no coating



Type 2: Monitors whisker penetration in through coating

Plate 1: Thick Sn, conformally coated

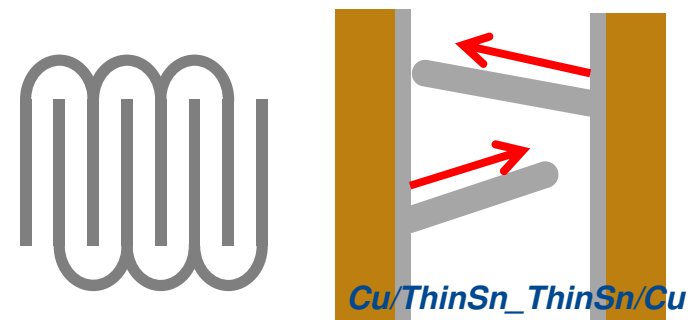
Plate 2: Thin Sn, no coating



Type 3: Monitors whisker penetration out from under coating and in through coating

Plate 1: Thin Sn, conformally coated

Plate 2: Thin Sn, conformally coated



Type 4: Control

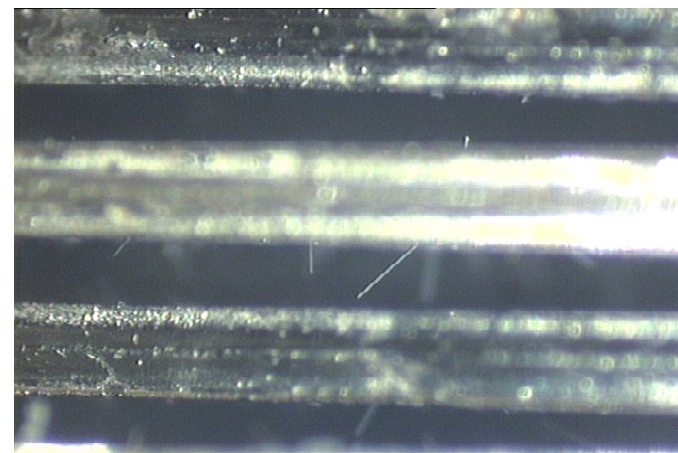
Plate 1: Thin Sn, no coating

Plate 2: Thin Sn, no coating

Coating Evaluation

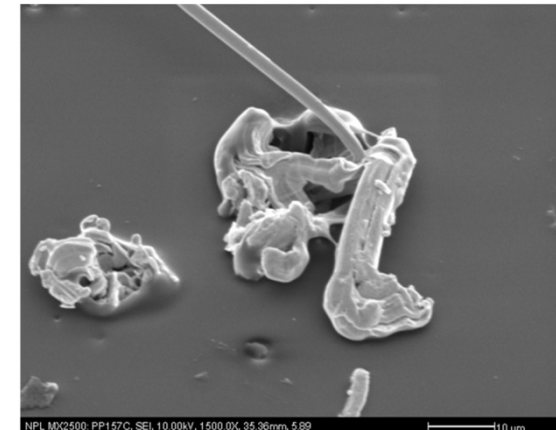
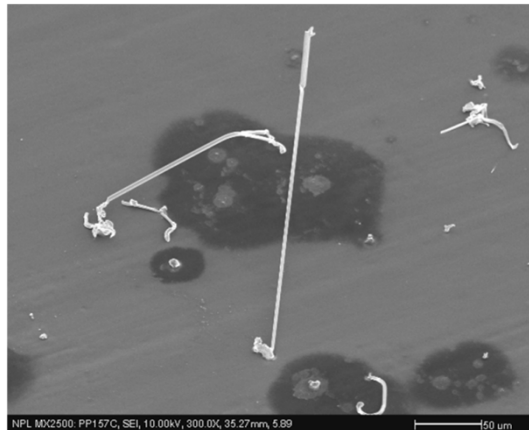
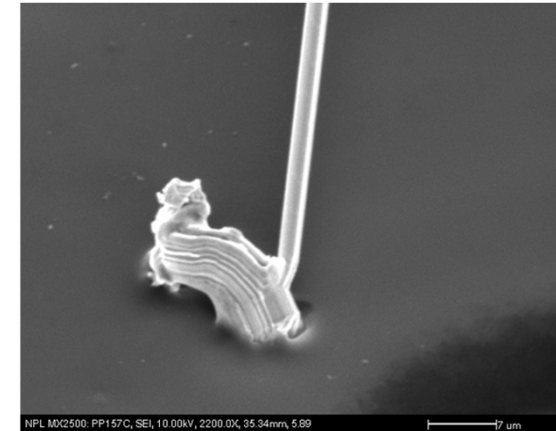
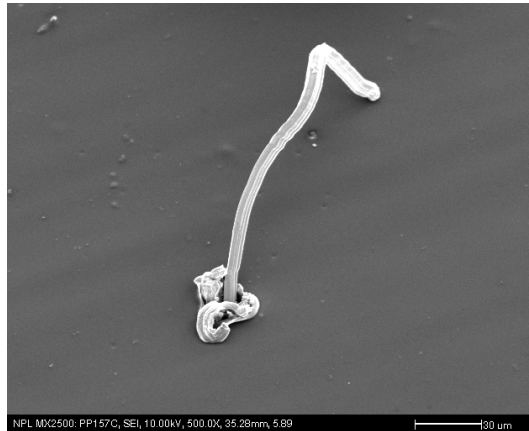
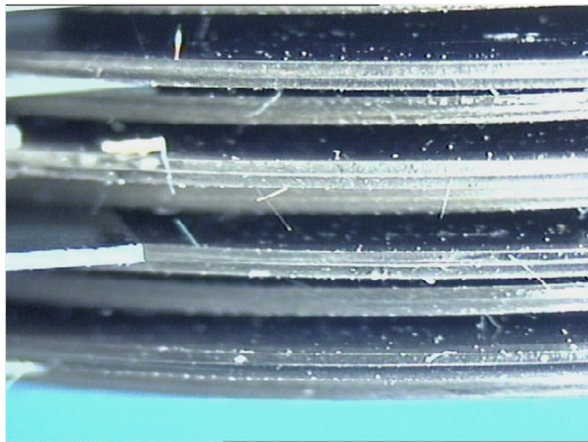
- 21 coatings
- Periodic electrical testing at 4V, 2 μ A
- All control samples exhibited electrical shorts within 14 days
- Aged at room temperature for 25,000+ hours

Coating	Thickness (μ m)	Coating	Thickness (μ m)
S1	15	P1	15
S2	20	P2	9
S3	488	P3	18
S4	19	P4	38
		P5	57
A1	6	P6	42
A2	18	P7	19
A3	20		
A4	11	U1	79
		U2	13

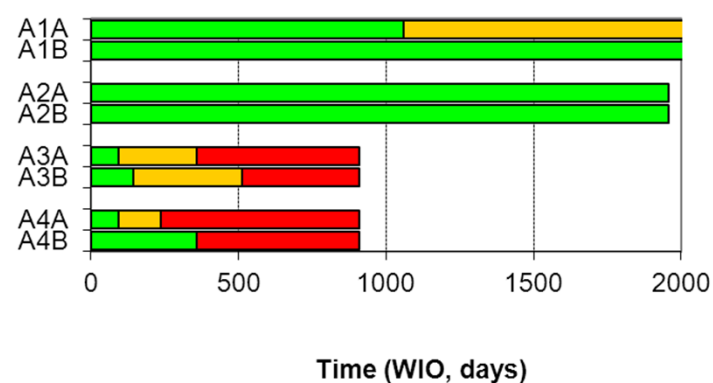
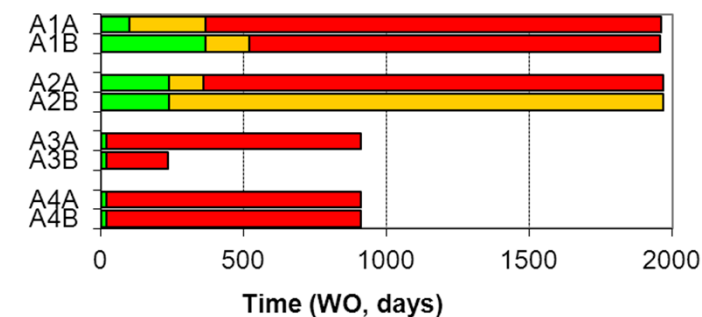
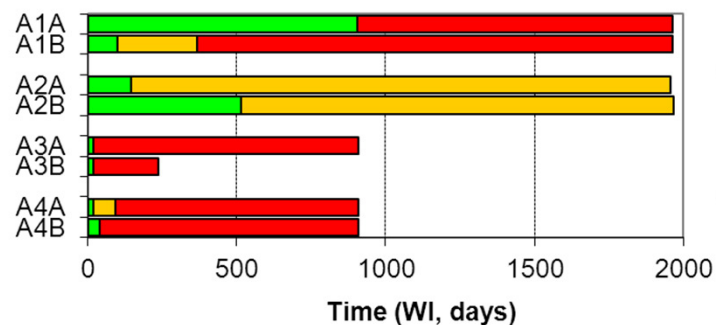


Source: NPL

Acrylic Coatings



Acrylic Coatings

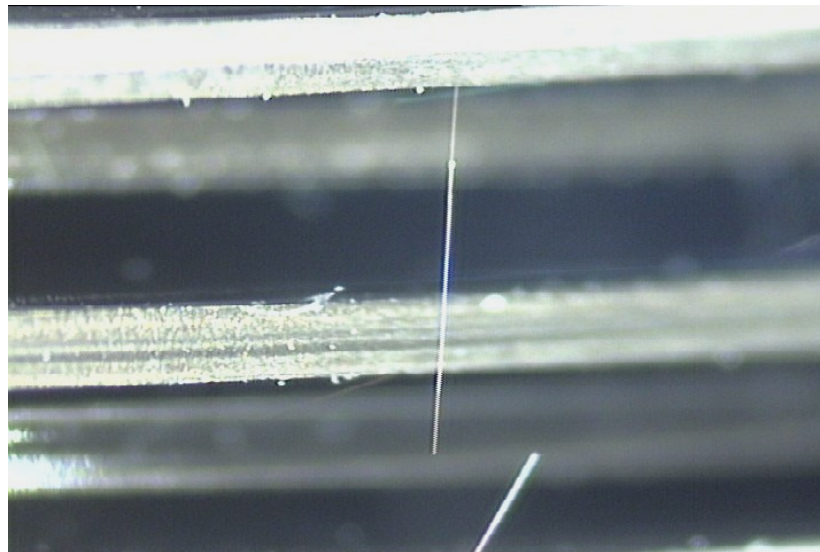


- All four coatings showed shorts during testing
- One acrylic coating did not short when coating applied to both surfaces of test vehicle

	A1	A2	A3	A4
Whiskers In Shorts	Yes	Yes	Yes	Yes
Whiskers Out Shorts	Yes	Yes	Yes	Yes
Whiskers In/Out Shorts	No	No	Yes	Yes
Edge Whiskers	Yes	Yes	Yes	Yes

Polyurethane Coatings

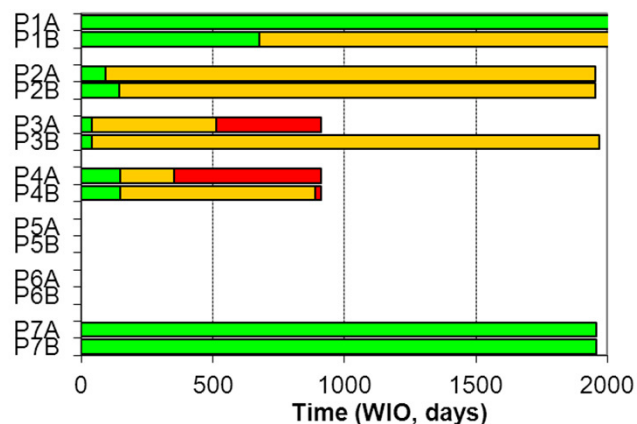
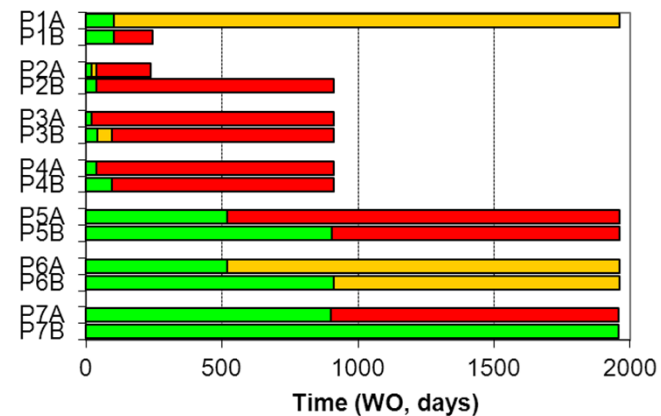
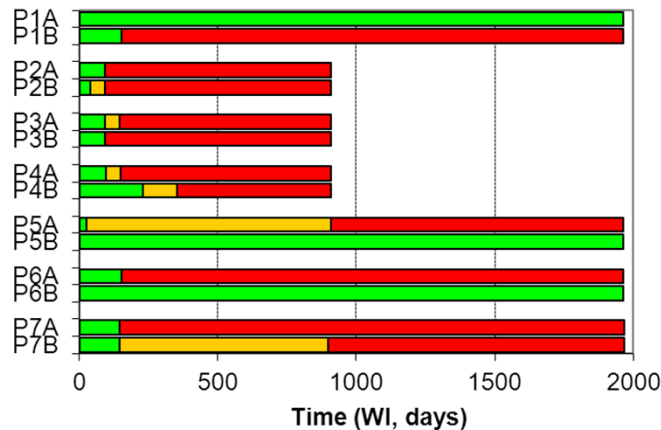
- All five coatings showed electrical shorts at some point during testing
- All five coatings showed whiskers at edges of plates
- No erupting whiskers were noted



Source: NPL

Polyurethane Coatings

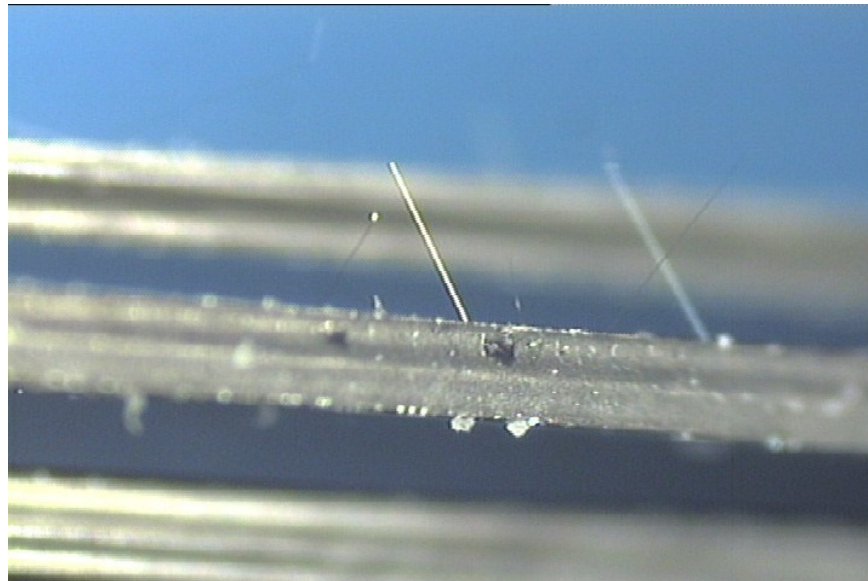
- All seven coatings showed shorts during testing
- One polyurethane coating did not short when coating was applied to both surfaces of test vehicle



	P1	P2	P3	P4/5/6	P7
Whiskers In Shorts	Yes	Yes	Yes	Yes	Yes
Whiskers Out Shorts	Yes	Yes	Yes	Yes	Yes
Whiskers I/O Shorts	Yes	Intermittent	Yes	Yes	No
Edge Whiskers	Yes	Yes	Yes	Yes	Yes

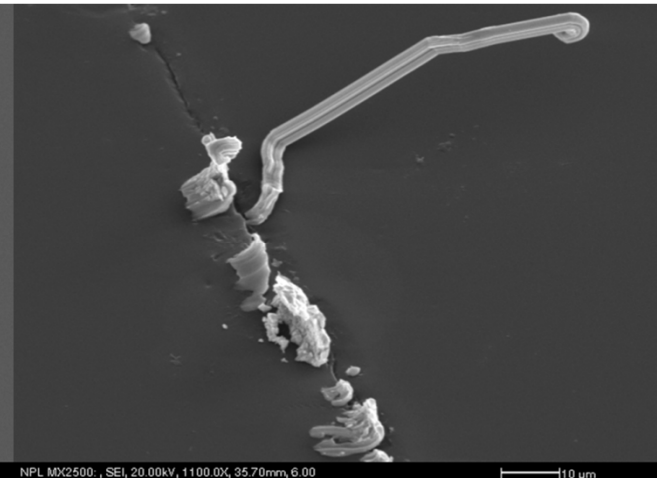
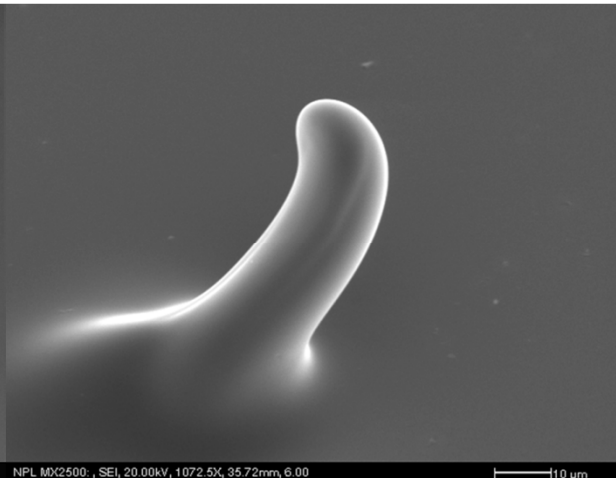
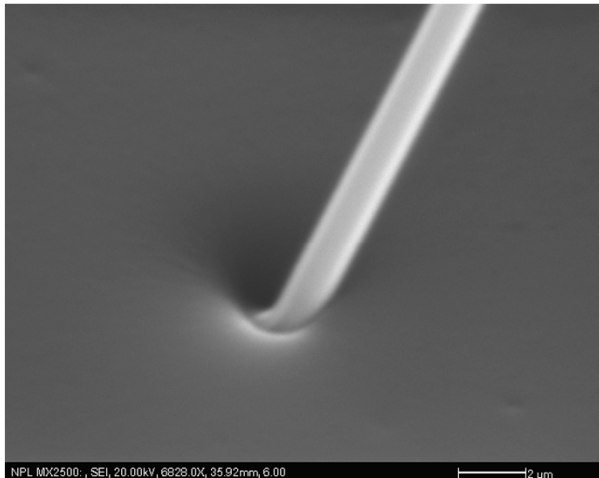
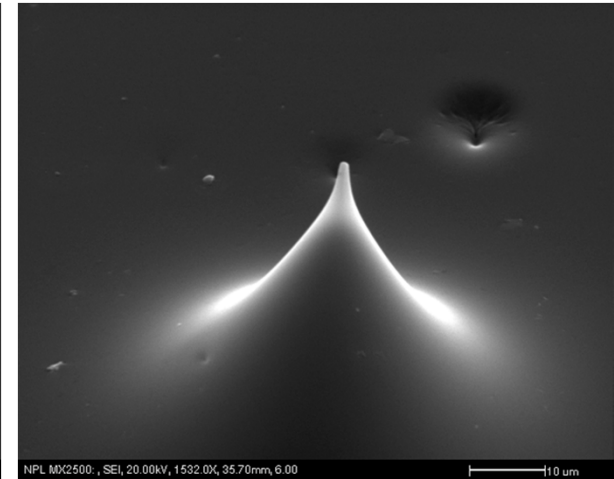
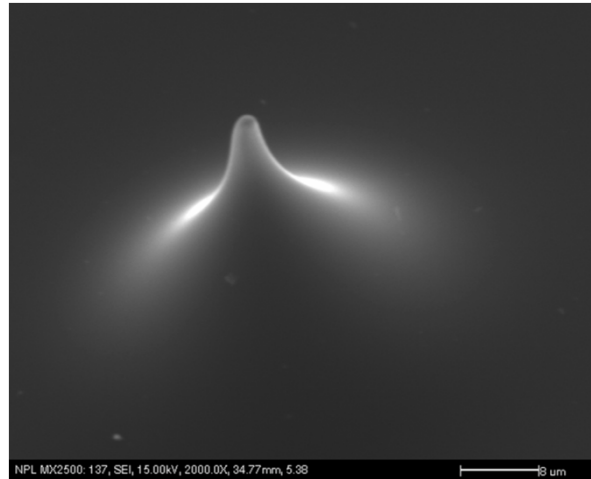
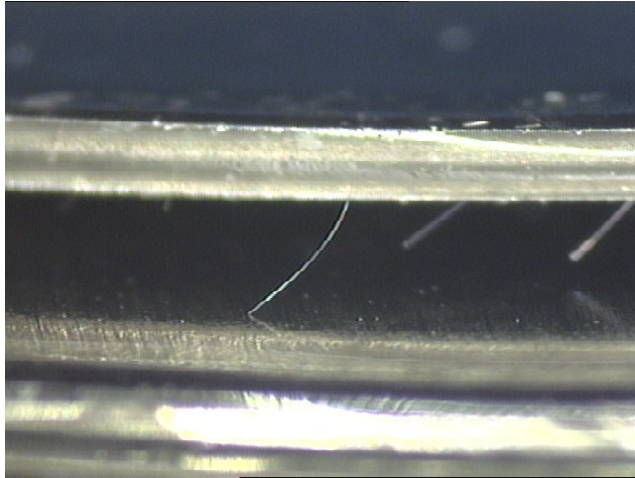
Silicone Coatings

- All seven coatings showed electrical shorts at some point during testing and whiskers at edges of plates
- No erupting whiskers were noted



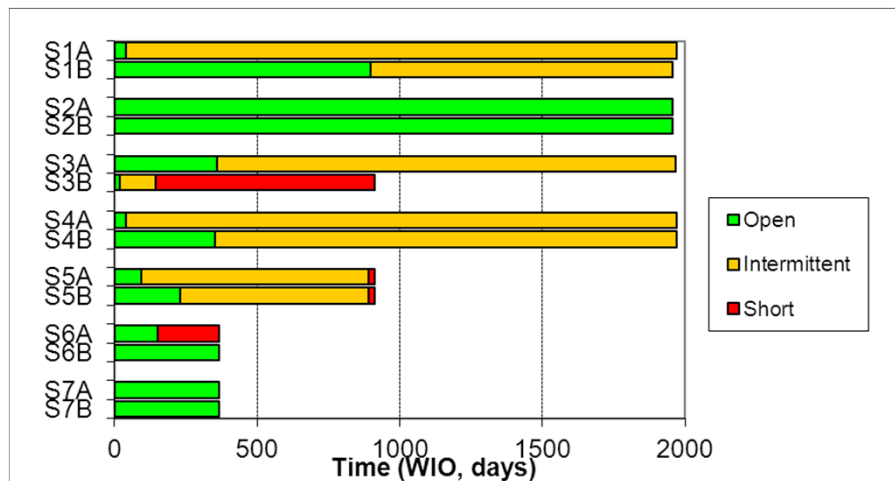
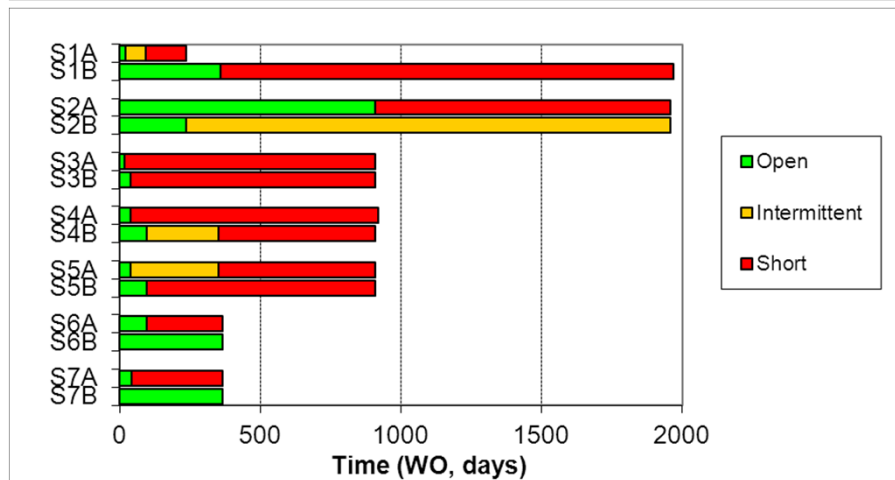
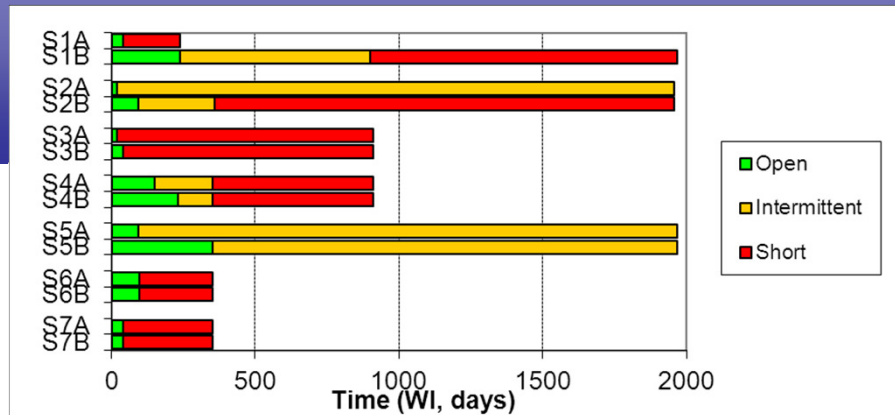
Source: NPL

Silicone Coatings



Silicone Coatings

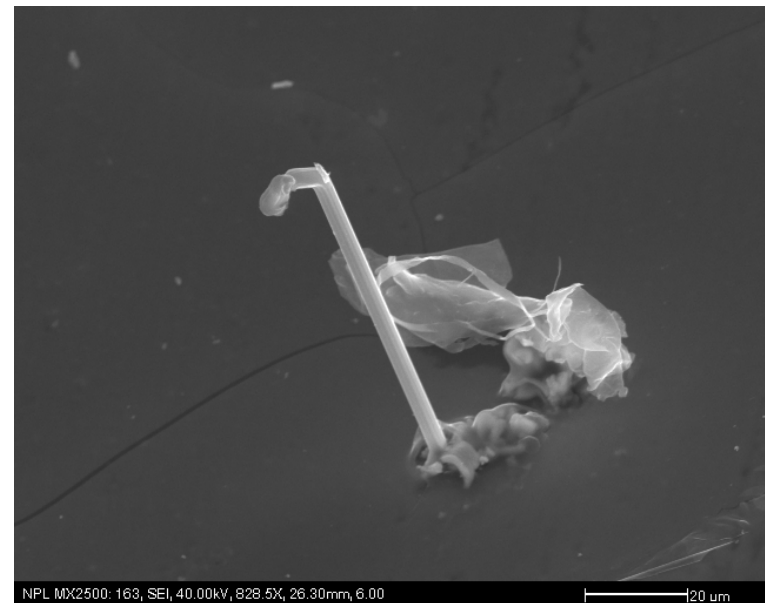
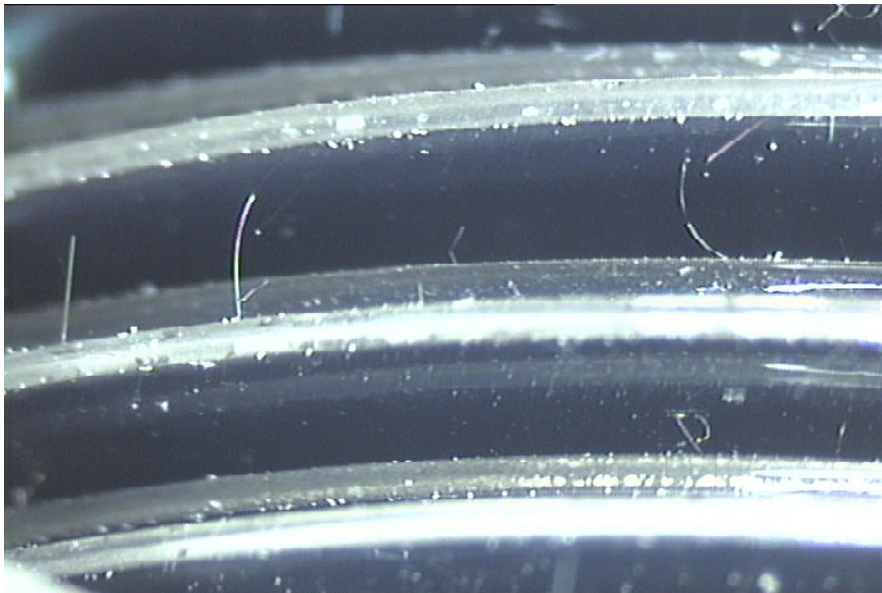
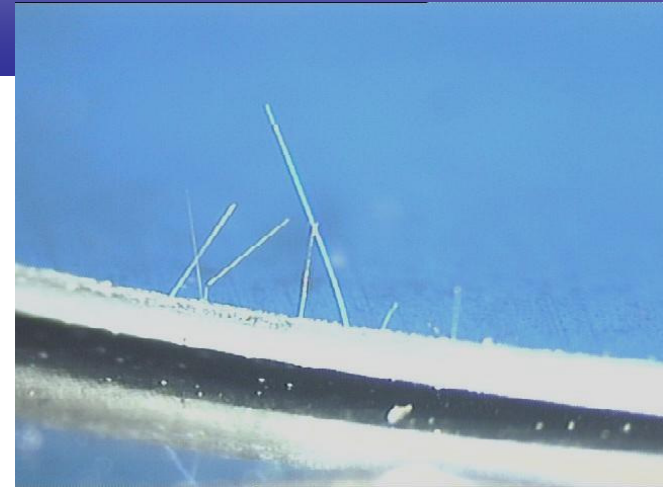
- All seven coatings showed shorts during testing
- One silicone coating did not short when coating was applied to both surfaces of test vehicle
- Second coating OK after 12 months (trial ended by partner)



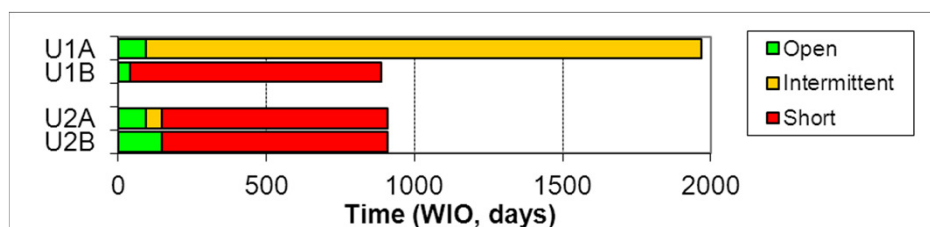
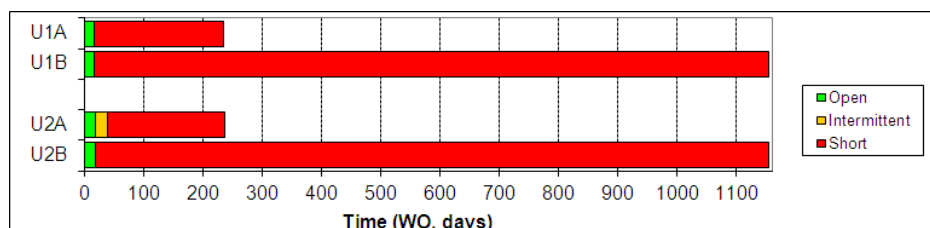
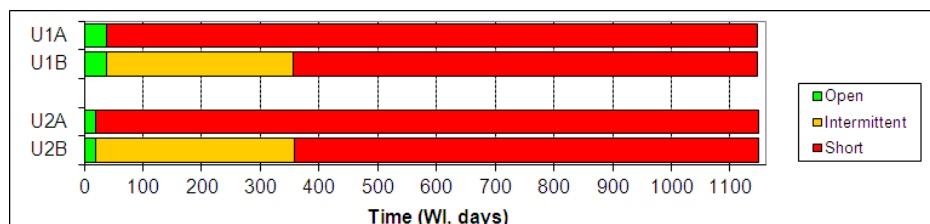
	S1	S2	S3	S4	S5
Whiskers In Shorts	Yes	Yes	Yes	Yes	Intermittent
Whiskers Out Shorts	Yes	Yes	Yes	Yes	Yes
Whiskers in/out shorts	Yes	No	Yes	Intermittent	Yes
Edge Whiskers	Yes	Yes	Yes	Yes	Yes

Urethane Acrylate Coatings

- Both coatings showed electrical shorts and whiskers at edges of plates
- No erupting whiskers were noted



Urethane Acrylate Coatings

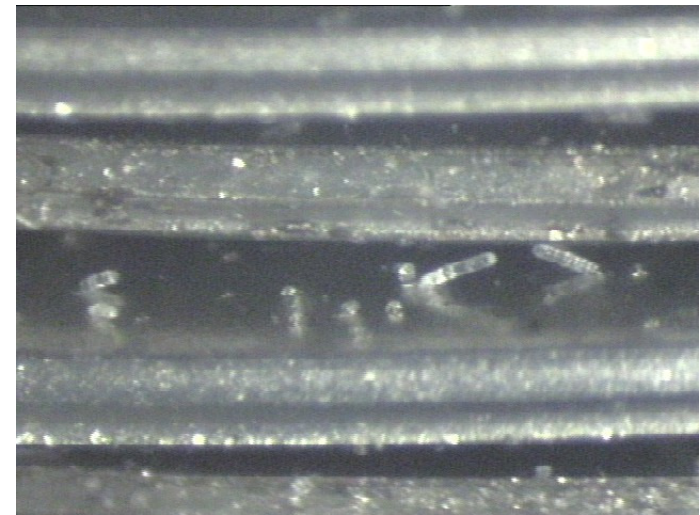
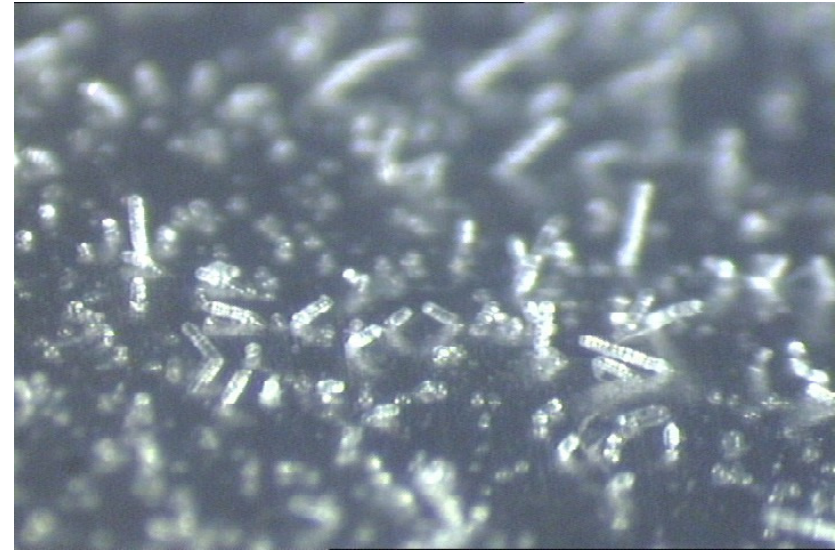


- Both coatings showed shorts during testing
- Both coatings shorted when coating was applied to both surfaces of test vehicle

	U1	U2
Whiskers In Shorts	Yes	Yes
Whiskers Out Shorts	Yes	Yes
Whiskers In/Out Shorts	Yes	Yes
Edge Whiskers	Yes	Yes

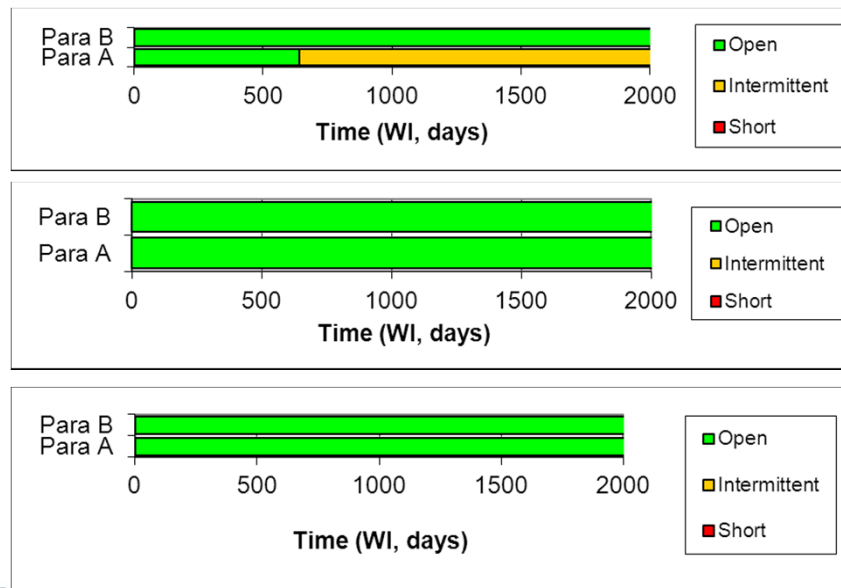
Para-xylene Coating

- Samples coated less than 48 hours after plating
- However, Sn coating had already started to whisker
- Coating provided encapsulation of each whisker
- Open circuit even where encapsulated whisker bridged plates



Para-xylene Summary

- Coating did not exhibit any whiskers at edges of plates
- No erupting whiskers were noted
- One sample became intermittent at 600+ days, (WO sample but whiskers developed on detector plate)



	X1
Whiskers In Shorts	Intermittent
Whiskers Out Shorts	No
Whiskers In/Out Shorts	No
Edge Whiskers	No

Whisker Summary

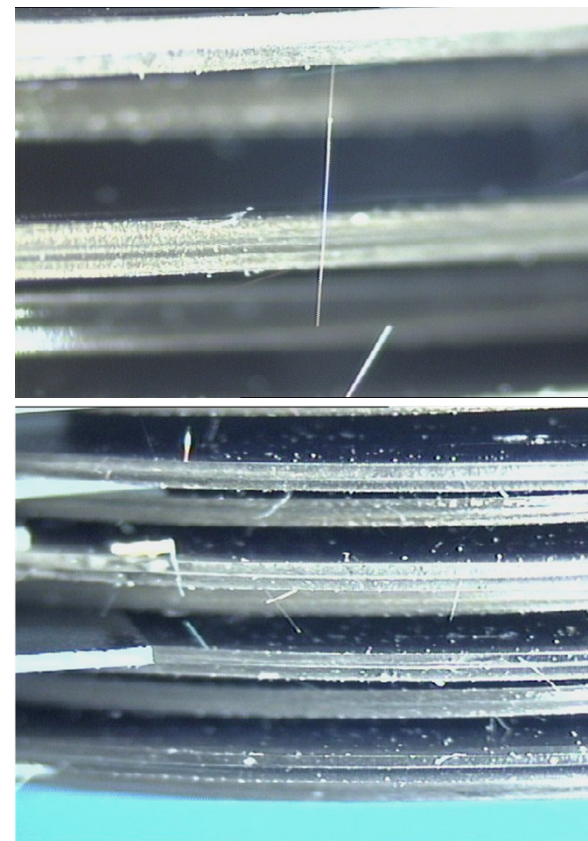
- All coatings suppressed the formation of whiskers compared to control samples
- Of those samples visually inspected after 5 years of testing, only 2 acrylic coatings were found to have whiskers erupting from under the coatings other than in damaged or poorly coated areas



Source: NPL

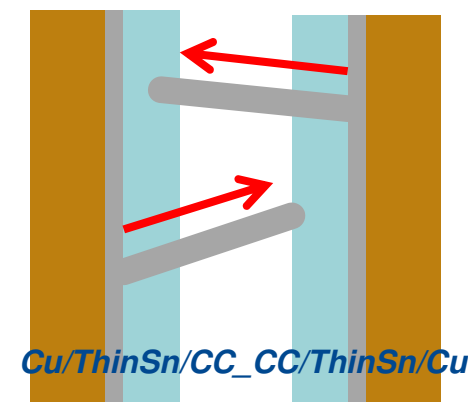
Whisker Summary

- Whiskers penetrating out from under coatings were found extensively in areas where the coating was thinner, or there were other coverage issues
- All the coatings evaluated except the paraxylene coating exhibited whisker growth from under coated plates in the region of the plate edges
- Coating coverage was an issue with majority of coatings evaluated
- PCB assemblies have a higher edge to surface ratio than parallel plate test vehicle



Whisker Summary

- Where both plates of the samples were coated, five of the coatings evaluated did not exhibit electrical shorts at any time during the 3 years of testing.
- These were two acrylics, one para-xylene, one polyurethane and one silicone coating.
- Of these only the para-xylene did not exhibit edge whiskers





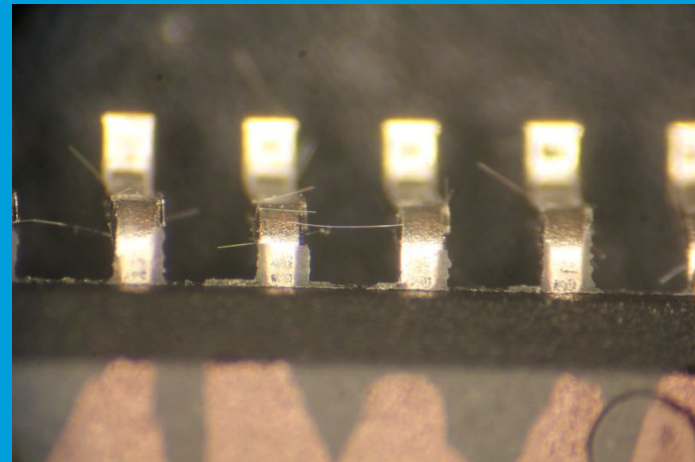
Whisker mitigation by coatings using an SOIC component test vehicle

Martin Wickham

Tel : 0208 943 7150

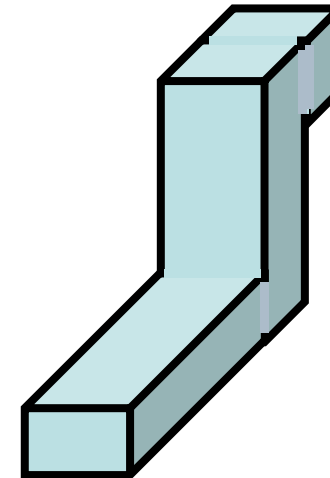
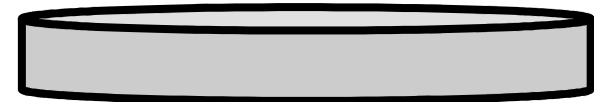
Mobile : 07831 629293

Email: martin.wickham@npl.co.uk



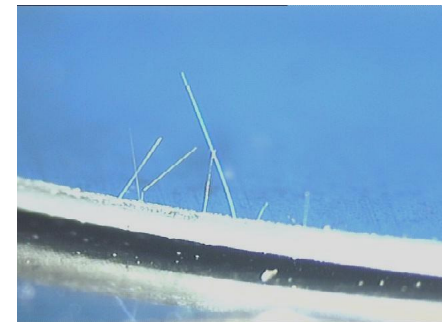
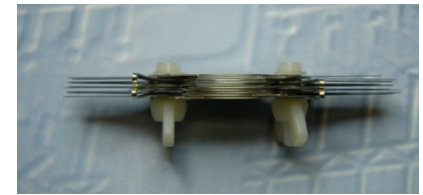
Real Assemblies

- Parallel plate test vehicle
 - Ratio edge length to surface area
 - 176mm : 1250mm²
 - 0.14mm/mm²
- SOIC14
 - Ratio edge length to surface area
 - 6.4mm : 1.64mm²
 - 3.9mm/mm²
- ~30x increase in edge length to surface plating



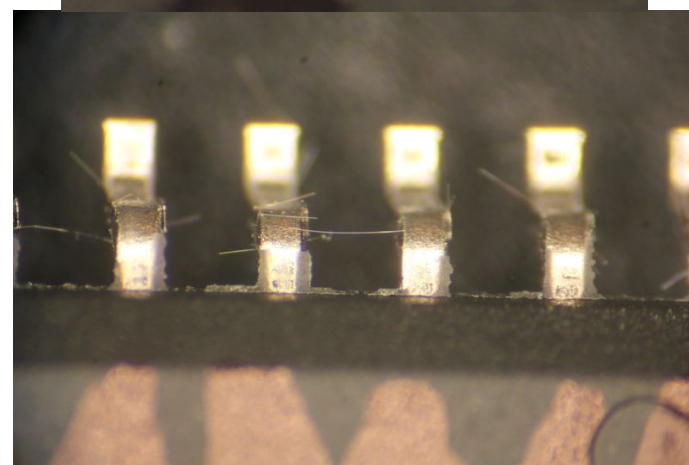
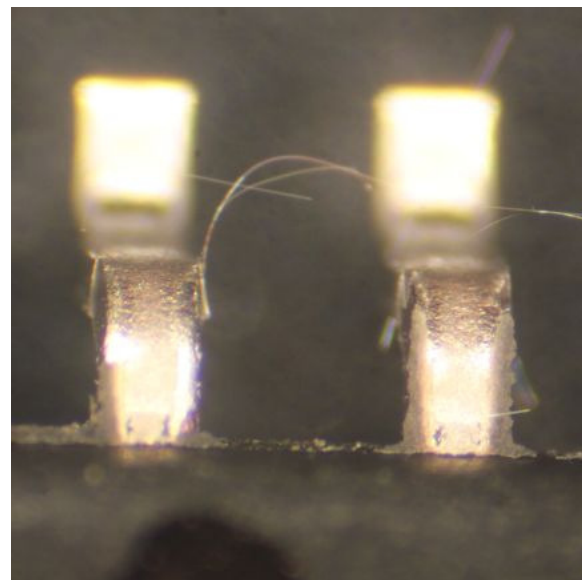
CCWM Lessons Learned

- Edges are important
- Plates are easy to coat
- Plates always handled by mounting screws by potential for damaging edges of structures
- Limited data set
- Whisker grow at any time
 - Many intermittents
 - Did we catch all the failures?
 - Whisker grows, makes contact, grows, breaks contact
- Was 4V high enough to locate all whisker touchdowns?

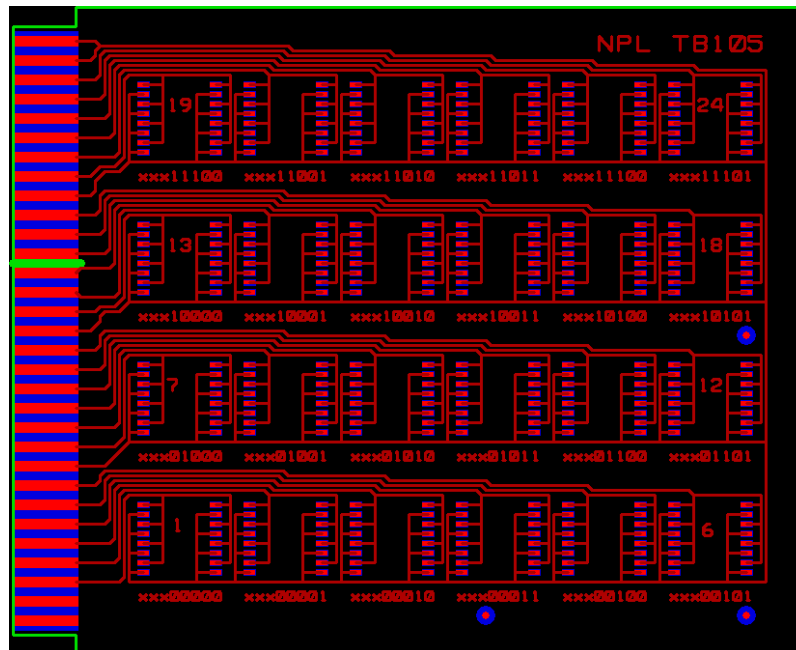
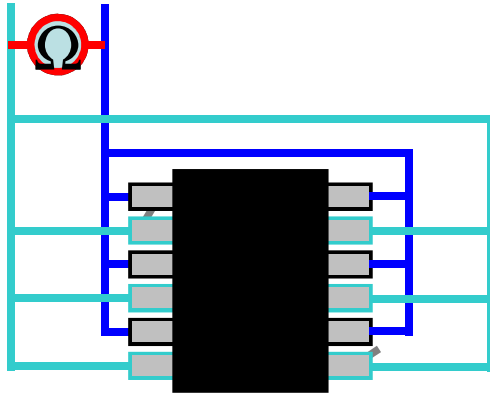


New Component Test Vehicle

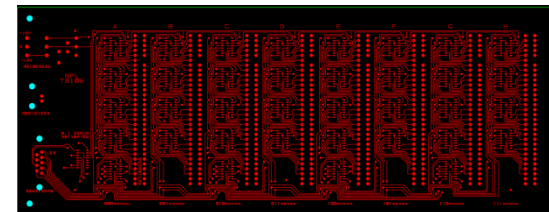
- NPL have collaborated with CML Microcircuits (UK) Ltd to produce a SOIC test vehicle using plating chemistry from previous project.
- The image shows whiskers that have grown in 4 weeks on uncoated, unmounted samples



Component Whisker Test Vehicle

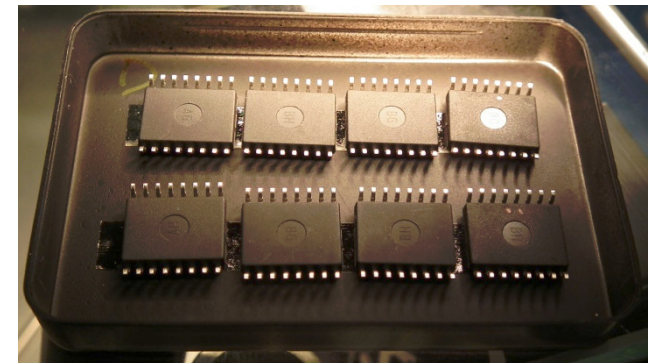


- Address individually each component
- 192 components per batch + controls + dummy boards for coating trials
- Assemblies delivered to partners for coating or
- Kit to partners for assembly
- Return to NPL for testing and analysis
- Constant monitoring (every 30 secs) for 12 months



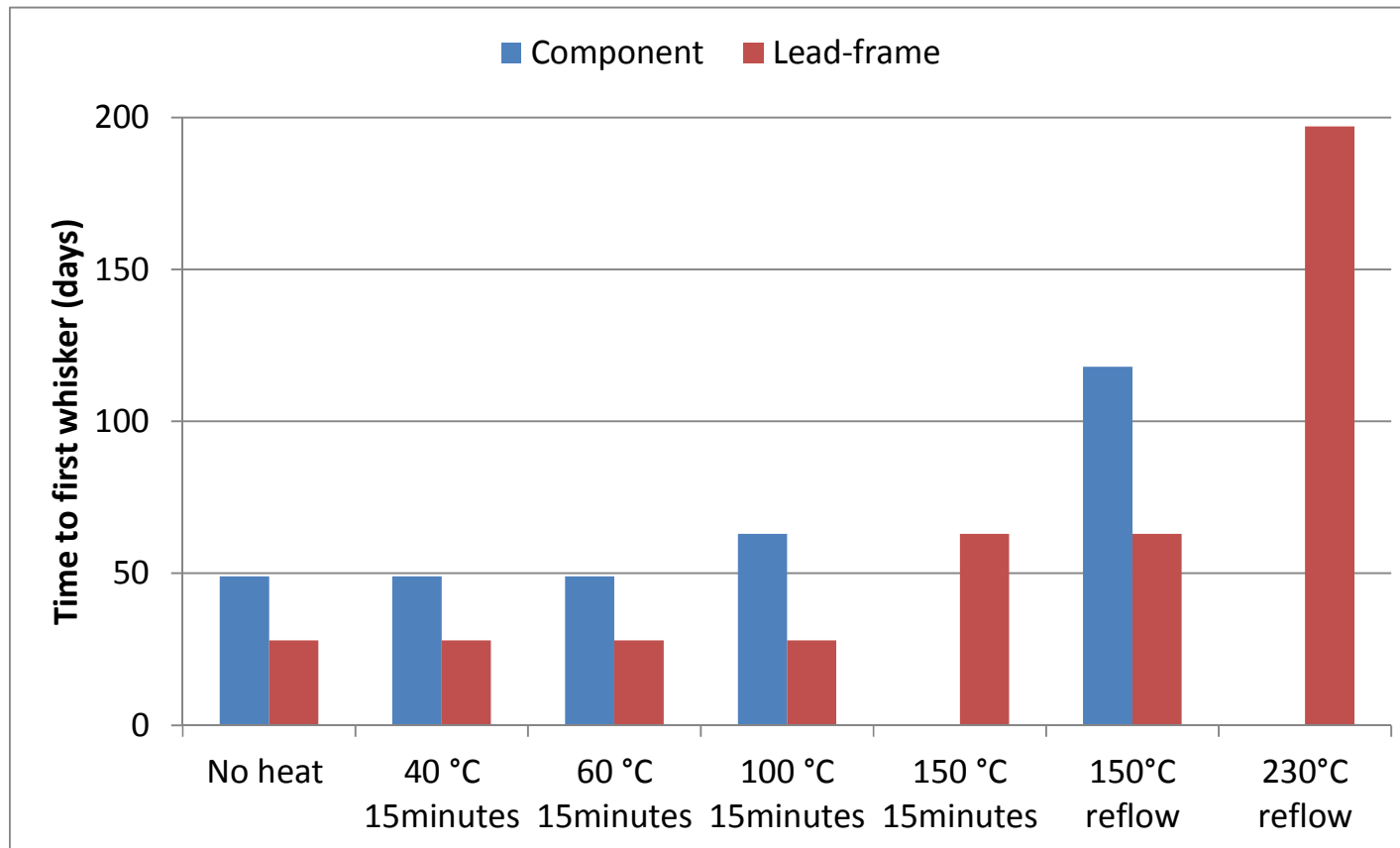
Trials to determine best assembly method

- Components fabricated using NPL plating
- Lead frames also retained
- Both subjected to range of temperature regimes to simulate assembly fabrication
 - As received
 - 40°C/15minutes
 - 60°C/15minutes
 - 100°C/15minutes
 - 150°C/15minutes
 - 150°C/reflow
 - 230°C/reflow



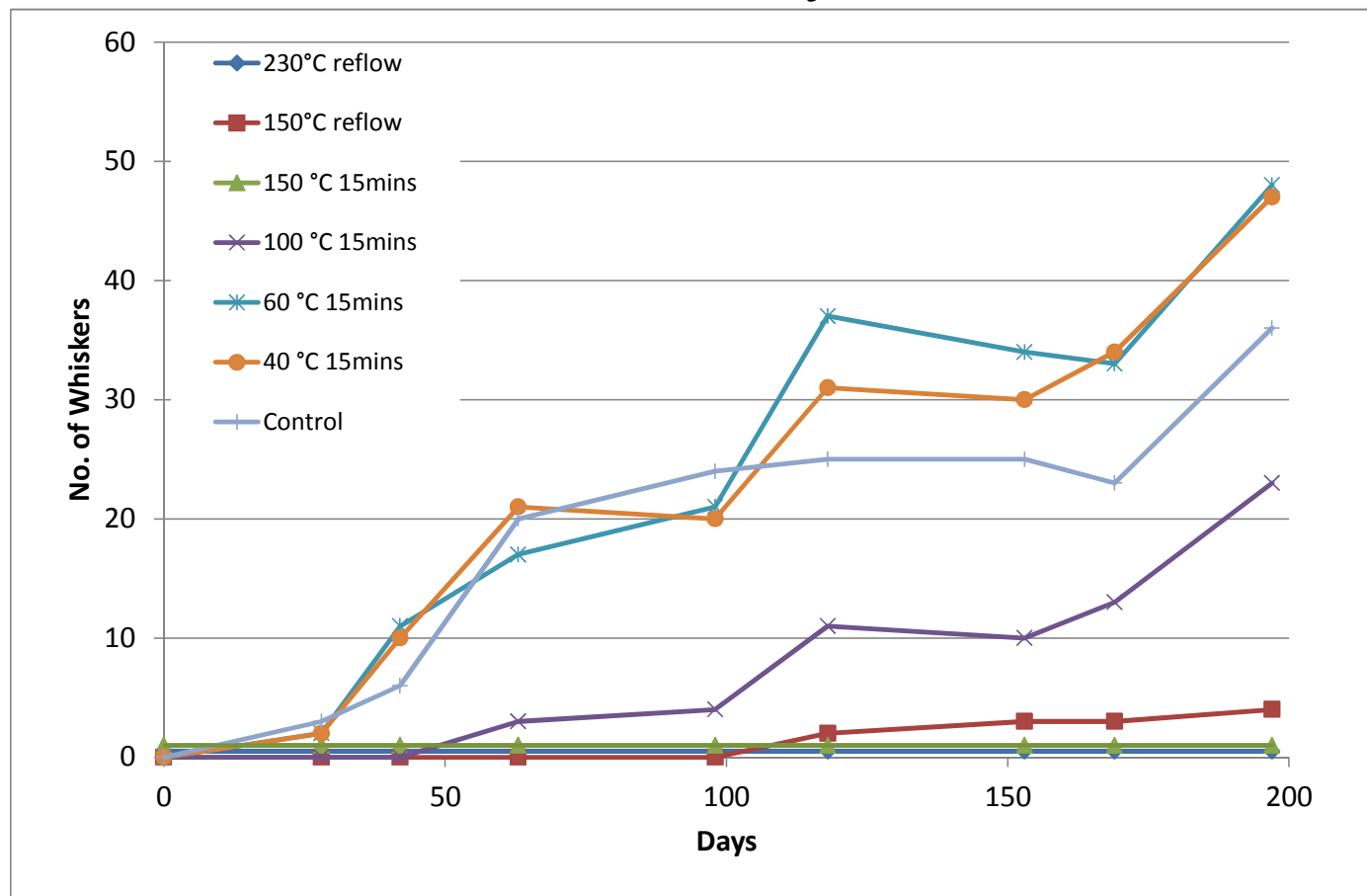
Time to first whisker – components vs lead frames

- Confirmation of delay in whiskering due to bend and crop operation (~30 days)



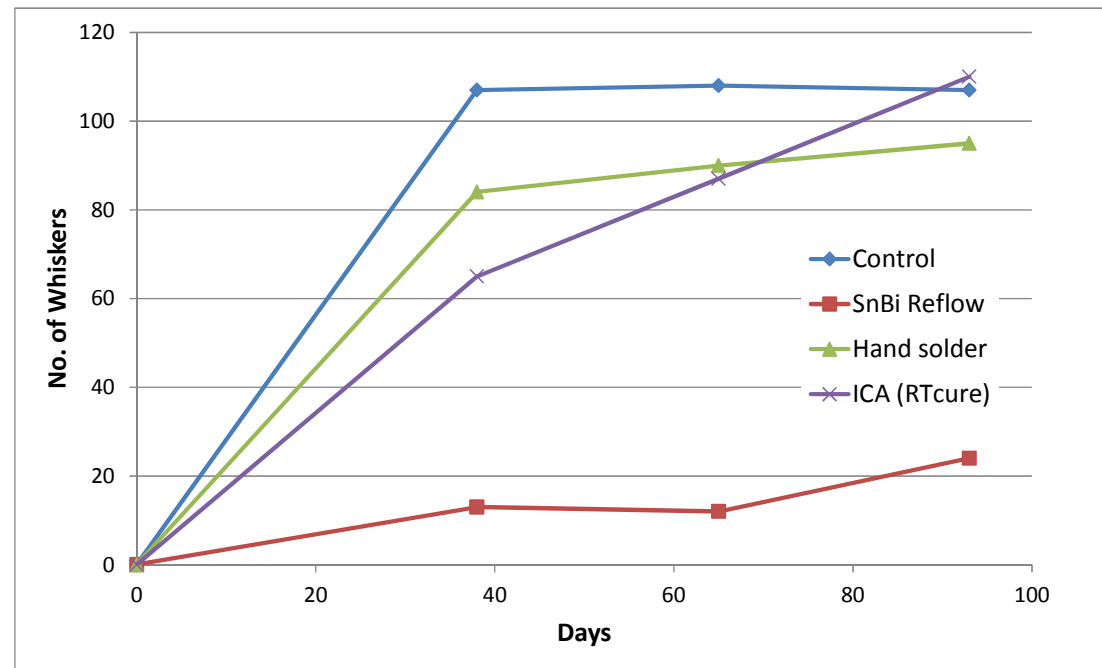
Whisker Growth Trial Components

- No whiskers after 200 days for 230°C/reflow or 150°C/15minutes
- Limited whiskers after 200 days - 150°C/reflow

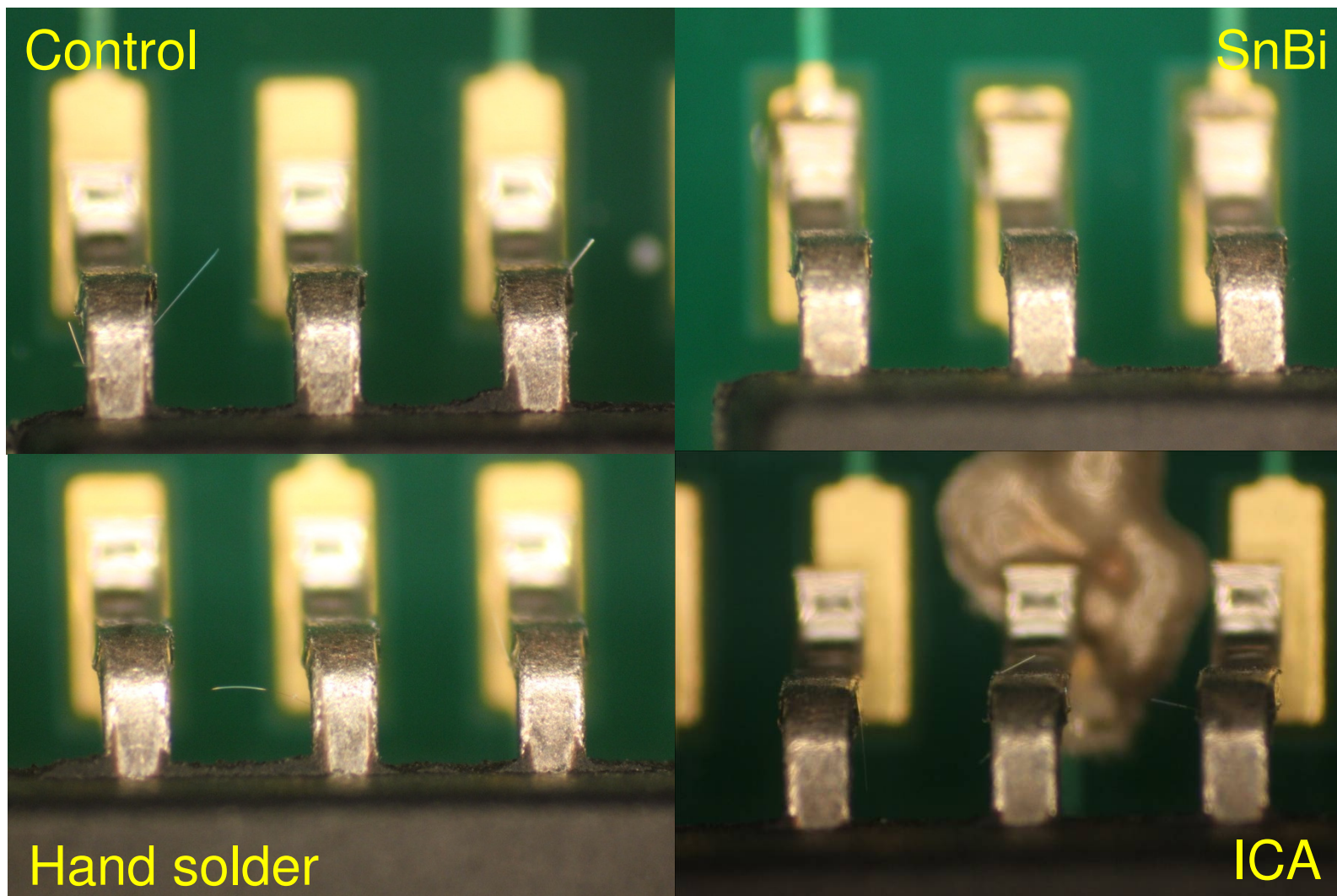


Whisker Growth Trial PCBs

- Components fabricated using NPL plating
- Components assembled to PCBs using range of techniques:
 - Control (component bodies glued with rapid araldite).
 - SnBi solder paste reflow.
 - Hand solder (SnPb) on corner legs only.
 - Isotropic conductive adhesive (room temperature cure).



Example Whiskering Trial PCBs

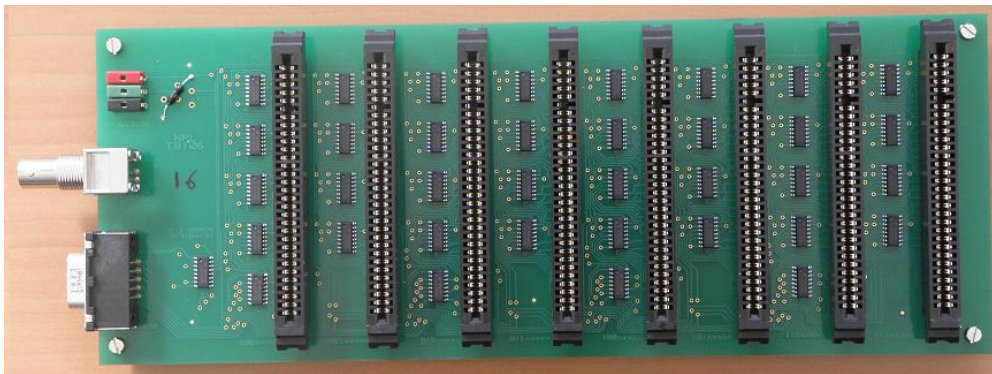


Whisker Growth Trial PCBs

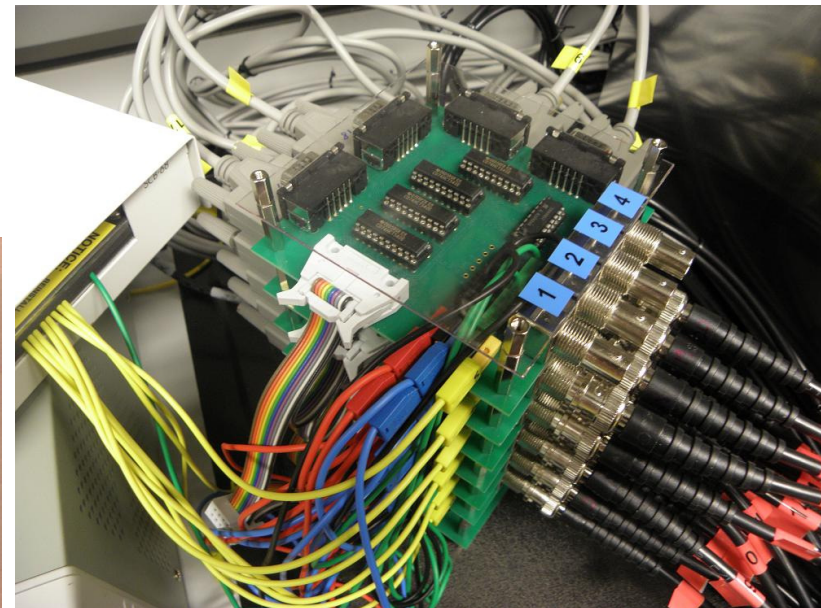
- Limited whiskers on SnBi reflowed assemblies
- Similar levels of whiskers on:
 - Control
 - Hand soldered corner joints
 - Conductive adhesive
- It should be noted that the whisker length on bent and cropped component leads appears to be less than for plated lead frames
- Hand soldering of joints has disadvantages
 - Difficult to maintain consistency with hand soldering operation
 - High cost of assembly operation

Hardware

- Build of mother boards completed
- Build of switching modules completed
- Docking bay build to hold all test boards.



National
Measurement
System



System Capability

- Currently 152 assemblies but can be expanded if necessary
- Current total of 58368 leads
- Each component tested every 15 minutes
 - Higher frequency possible but currently felt to be unnecessary
- Test voltage = 15V
- 1M Ω resistor in series to limit current to 15 μ A
- System will detect a whisker short at 1M Ω or below on any one of 3648 components (each individually addressed)

Project Outline Phase 2

- Test vehicle storage and electrical monitoring for 12 months
 - Status report after 6 months
- Inspection and characterisation of whisker penetration of coatings
 - Electrical test
 - Visual inspection of shorted component
 - Example SEM images (destructive) subject to partner agreement

Coatings
Acrylic
Polyurethane
Urethane Acrylate
Paraxylene
Fluorocarbon
ALD
Assembly evaluation

Partners
HMGCC
Rockwell Collins
HK Wentworth
AEC
Humiseal
MBDA
Rolls Royce
Semblant Ltd
Lockheed Martin
NSWC Crane
Raytheon Integrated Defense Systems
Sagem Defense
SSTL

Thank you for listening
Any questions?

Martin Wickham

Tel : +44 (0) 208 943 7150

Mobile : +44 (0) 7831 629293

Email: martin.wickham@npl.co.uk

